THE

AMERICAN NATURALIST

VOL. XLVI — *January, 1912* — No. 541

THE INHERITANCE OF COLOR IN SHORT HORN CATTLE

II.

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In order to adduce further evidence bearing upon the problem of the inheritance of color in cattle the following observations on the occurrence of dominant and recessive whites in other animals are reported. Many species of animals have some strains with solid white coats and others with coats made up of both white and pigmented areas. The white in such latter coats is always possessed in a somewhat definitely arranged and progressive system of areas characteristic of each species, spreading from the first of these areas until the entire body is covered. Thus in the guinea pig the whitening process begins with the underline and large "centripetal" body blotches and spreads until the hair, skin and body pigments are entirely removed the eye and the "centrifugal" coat pigments persisting the longest. In the domestic cat the process begins with the anterior underline and collar, from which areas it spreads in large blotches. The rabbit's pigment areas behave similarly. With the particolored dog of any or no breed, the whitening process begins with a white line down the middle of the face, a

white chest, a white collar and generally a white tail tip. With cattle of all breeds and crosses possessing broken color patterns the process begins with a white belt at the rear flank, continues with another at the fore flank, a white underline and a white forehead. With horses of the English breeds it begins with a blaze face and white feet, continuing with large body blotches. With the French and the desert breeds it seems to begin with a "dappling" of the body hair—dark pigment persisting longest on the legs—and continues through a lighter "dappling" to white, the skin remaining black, while the sharper whitening process seems to follow the sequence observed in English breeds. In the case of the piebald negro the median face line is quite noticeable. Thus, while there is for each species a characteristic pattern, there is in reality a somewhat common pattern in all species of mammals possessing particolored individuals. This common pattern is described as follows: White line down the face, white underline, white anterior belt or collar, white rear flank belt and white feet and switch. These white areas may, in animals possessing but little white, be represented by several smaller areas, but always near the median line of the areas white in the larger pattern, which smaller areas may fuse as the pattern becomes coarser. Thus the white nose and forehead in some cattle may in others make a continuous white line down the face. The white spreads from the areas just defined with much the same sequence as a fire would spread over a "hide-shaped" meadow, starting at the centers homologous to the first white areas of the coat. In all cases the pigments seem to persist the longest in and about the eyes and ears and at the buttock—the "centrifugal areas" mentioned by Castle.

The coat of a white Shorthorn may consist of: (1) Solid dominant white covering red (quite rare); (2) some definite coat areas dominant white covering red, others albinic white (very common); (3) some areas albinic white, others dominant white not covering red

(quite common). In eye color the white Shorthorn is either blue or brown; the roan and red Shorthorns are always brown eyed. The characteristic pigment areas may, in domestic animals, become subjected to rigid selection, resulting in modified forms—as the white belt of the Dutch belted cattle and the white head, neck and underline of the Hereford. Approximations to the former and to the reciprocal of the latter modifications (*not* of the species pattern) are commonly observed among Shorthorns. In general, however, color patterns are quite characteristic of the species and are quite persistent. Greatly modified patterns are seldom seen and, moreover, the reciprocal coloration is *never* seen.

Not only does the whitening process begin at definite centers quite specific for each species, but it also seems to be definitely progressive in tissues carrying pigment. Thus, the whitening process begins in man with the skin, extending to the hair, the iris, and finally the choroid. Partial albinos often have blue eyes—the absence of the iris pigment but the presence of the choroid. In the guinea pig the hair and skin pigments generally seem to disappear before those of the eye. Castle[16] reports a guinea pig with an area of red hair underlaid by a patch of black skin, and observes that a white dog may have a patch of pigmented skin somewhere under the hair coat. Similar phenomena are found in all species having particolored strains. It is a matter of common observation that a white patch of skin or hair unsymmetrically covering but one eye of a dog or horse sometimes gives this animal a "glass eye," *i. e.*, unsymmetrical eye color, the blue eye being surrounded by white hair and skin while the dark eye is surrounded by dark tissues; this, however, is not always the case, for many times both eyes are dark.

In horses and cattle the hair is first whitened, then the skin, the iris and the choroid follow in the order named. A black horse or cow may have a spot of white hair on some portion of the body; it may be entirely underlaid by

[16] "Heredity of Coat Characters in Guinea-pigs and Rabbits," p. 46.

black skin—this is especially apt to be the case with small spots, or under the center of such an area there may be a pigmentless skin—generally characteristic of the larger areas, while its margin is underlaid by black skin, but *never the reverse.* In some instances, however, the pigmentless skin and hair areas exactly coincide. The hoof of the white foot of a horse or cow is generally white, that of the dark foot always black; however, quite often a white patch or streak will extend to the hoof and then come to an abrupt end, the hoof continuing in a vertical line the same pigment possessed by the skin immediately underneath the lighter hair patch giving rise to the hoof; thus the hoof is as dark or darker, but never lighter, than the hair patch immediately above. In spotted horses it is observed that a white coat spot crossing the mane will sometimes whiten it, while in other instances it will not. Mr. Chas. E. Burns, the pony breeder of Peoria, Ill., writes:

> We naturally expect spotted Shetlands from spotted ancestors but can say that very frequently I have bred a spot to a spot and the offspring has been a solid color. On the other hand, I have very frequently had spotted colts from solid-colored parents. The fact that there is spotted blood in the ancestors of the solid colored ponies accounts perhaps for the spots, and *vice versa.* There seems to be no sure rule in governing the color of a Shetland. The mane and tail are not always the same color as the adjacent color patches of the coat. Very frequently I have seen a white mane come right out of a black patch, although as a general rule the color of a mane is the same color as the adjacent coat of the pony. This is general also as regards the tail, but very frequently, as I say, a black tail comes out of a white spot, or a white tail out of a black spot, and often the tail is both black and white.

Mr. C. R. Clemmons, of Coffeyville, Kans., writes:

> I have been breeding spotted Shetlands for twenty-five years. I find that many mares of a solid color will bring spotted colts quite regularly when bred to a spotted stallion having considerable blood from these colors but every now and then there will be a foal of perfectly plain color as the result of this same mating. I am of the opinion, however, that a spotted color breed could be obtained by breeding in these colors and perhaps inbreeding.

The mane and tail of a spotted Shetland are not always of the same color as the adjoining patches of the coat, there is sometimes a distinct color line between the mane and tail and the coat."

Mr. W. A. Long, of Greeley, Ia., offers the following evidence:

We have no recollection of seeing any roan Belgian stallions with white manes and tails. Our experience with the roan stallions has been that the colts are principally roan. We have in mind one roan stallion that we imported that sired 68 colts one year and they were all roans out of all colors of mares. We handle many chestnut horses with white manes and tails, and they sire principally all chestnut colts, but there will be some bays and other colors, as all colors are represented in the Belgian breed. They do not all sire the white mane and tail but many of the colts are so marked.

Mr. A. W. Hawley, of Pioneer, Ia., says:

I had a beautiful light mane and tail chestnut from a black Belgian mare and a black Percheron stallion.

The roan stallion above referred to doubtless corresponds exactly to either type No. 7 or No. 8 of Shorthorn cattle, the dominant duplex white always persisting and the hairs of the second network remain either red or black, making the familiar "red-roan" or "blue-roan," depending upon the gametic composition of the dam, epistacy and the laws of chance. Belgian horses resemble Shorthorn cattle in that they are a breed of many colors, including the interesting roan. Indeed, the roan, silvered, barred, "agouti," mottled, piebald, flea-bitten and other variegated types of animals of all species so characterized seem to behave in inheritance in a manner typified by the roan Shorthorn.

While the mane and tail are generally of the same color as the adjacent body coat, there is often a pigment differentiation—the coarser hair whitening first. This phenomenon is also exemplified in the case of black or spotted cats, which often have white "mustaches" growing from black or dark skins and coats, but never the reverse. Among wild animals the silver fox and the

silver-tipped bear present instances of the whitening process beginning with the hair tips. Recall, in this connection, the lighter colors sometimes present on the hair tips of the cattle crosses reported by Professor Wentworth, and the "albinic" superficial tissues of the Silkie fowl with its pigmented deeper tissues. Thus it seems that with mammals and with some birds the whitening process begins with the more superficial tissues and continues to the deeper ones; with mammals, coarse hair, fine hair, skin, nail, sclerotic, iris, choroid, being the order followed.

Permit a short digression into the plant kingdom. Of the two or three hundred varieties of the dent corn, all of the yellow and red varieties have red cobs and all of the white varieties have white cobs, with the exception of St. Charles County white, which has a red cob.

Jack-stock breeders in America are making an effort to establish a race of black animals with white points, and the following evidence, while primarily bearing on this problem, is typical of the behavior when not involving the whitening process of pigments of domestic animals. In the *Breeders' Gazette*, May 10, 1911, a breeder states this problem:

> A jack is of good size, well made in every way but he is of maltese color. He is exactly the color of his sire and his sire was a popular jack in his locality and a first-class mule-getter. Is this color a real objection? What is the prevailing color of mules sired by the maltese-colored jacks?

To which L. M. Monsees, of Sedalia, Mo., the jack-stock breeder and authority, responds:

> I have seen some extra good mule jacks of the maltese color. A maltese or blue jack, if from a good, large family of good blood, and himself a good individual, will no doubt prove a good breeder. He should be expected to get good solid colors—bays, blacks, browns, blues and chestnuts.

Thus it seems probable that, when different parental pigments, but not the whitening process, are involved, the

pigments of the offspring are due to either a simple Mendelian mixture of various dilutions of parental pigments with their resultant hypostatic effect, or to minor reaction between the determiners presented by the two parents resulting in modified pigment bodies.

Barrington, Lee and Pearson's study of color in the gray-hound—*Biometrika,* 1904—presents evidence that might well be given such an interpretation. Their elaborate tables measure accurately the correlation of the color of ancestry and offspring in this animal, but they do not explain what takes place in the zygote upon its creation by the union of two somewhat differently organized and differently descended gametes; nor do they clarify the conception of gametic organization. It is, however, primarily a study in the mathematics, not the chemistry, mechanism nor biology of inheritance.

The black mane, tail and feet of the bay and of some blue roan horses, and the white mane, tail and feet of the chestnut Belgian seem to indicate that in horses the whitening process may proceed somewhat out of synchronism in its tissue and area sequences. The white mane and tail seem to be causatively correlated with the chestnut coat of the Belgian, which white seems to be recessive to the heavier pigments. Moreover, when the destroying process attacks highly organized pigment bodies, is the destruction always complete? May there not be resting stages in this destruction and may not the series—blacks, browns, bays, chestnuts, sorrels, duns and creams—besides being different dilutions and hypostatic effects of different pigments, represent these stages? Furthermore, may there not be a pigment sequence as well as an area, tissue and ontogenetic sequence involved in the whitening process? And are the chestnut, sorrel, dun and cream pigments the ones most readily destroyed by the antibody?

Note in this connection that in dogs and other mammals having some individuals with black, tan and white areas, the black areas are quite often bordered by a zone of tan,

and often small tan but rarely small white spots are found within the larger black areas. These are the conditions expected if the tan were an intermediate product resulting from the attack of the destroying antibody upon the determiner for the heavier pigmentation. The sequence of color bands along the hairs of the wild and agouti cavies, viz., heavily pigmented brown tip, yellow band and leaden base, is also suggestive of the same derivation of the yellow.

Besides an area progression and a tissue progression involved in the whitening process in animals, there is also an ontogenetic progression of the same process. In man and in many pigmented animals a progressive grayness, called "senile white," comes with old age, in some strains earlier than in others. White horses—dominant white—are always born pigmented, but soon change to white—juvenile white, it might well be called. White Leghorn fowls are hatched white and, save for a senile deposit of pigment, remain so.

The observed facts seem to demand intra-zygotic inhibition and reaction quite closely approximating the following hypothetical processes: In a germ cell of some heavily pigmented animal, say, of a black Angus bull, let there be a specific chemical determiner (N) for black pigment in the entire skin and hair coat and in the sclerotic, choroid and iris. This determiner reacts like and indeed may be a body closely related to the enzymes, in that both may be weakened, exhausted, or totally inhibited without being impaired or destroyed by the presence of varying amounts of an antibody of some sort, still greater amounts of which set up chemical reaction resulting in partial or total destruction, depending upon the relative quantity and intimacy of the two bodies in much the same manner as trypsin is totally inhibited but not destroyed by .05 per cent. of lactic acid, but is totally destroyed by .1 per cent. of hydrochloric acid.[17] In the germ cell of a white mate of the aforementioned

[17] Green, "The Soluble Ferments and Fermentation," p. 198.

animal let there be an antibody (W) (analogous to the acids in the above illustration) substituted for and placed homologously to the determiner (N) for black pigment, which antibody is capable of weakening, inhibiting and finally of totally destroying the determiner according to the relative quantity and intimacy of the two bodies. Let this antibody (W) exist in a quantity large enough to totally inhibit the ontogenesis of N, but not to effect its destruction. Now let fertilization take place; the F_1 generation is white. A white so behaving is said to be dominant. Because there was only inhibition of N with no chemical reaction between N and W, and segregation may take place in later generations according to the familiar formula, F_1 is said to be simplex in reference to this unit character. If, however, the antibody in quantity sufficient for inhibition makes its intrusion de novo into a gamete possessing a determiner for N and this mutant germ cell meets another of similar origin or descent, and the total amount of the antibody is still sufficient to cause reaction, a duplex dominant white offspring results, which, mated with one of its own kind, will establish a race of white animals, inhibiting somatically in heredity until further disturbance by extraneous intrusion or by hybridizing the determiner N. Animals of this sort upon hybridizing—as Davenport has shown in his white Leghorn crosses—may be made to yield the ancestral coloration. If the antibody exists in quantity sufficiently great to inhibit absolutely all of the determiner, with an excess sufficient to cause chemical reaction destroying a portion of N, then partial albinism results and the offspring, although entirely white, will possess some definite areas of dominant white covering pigment, and others of albinic white, breeding exactly like the white Shorthorns designated in this study as type No. 6. If, however, in the germ-cell of the white mate a still larger quantity of W be present (exactly large enough to effect the total destruction of N) upon fertilization N and

W react and are destroyed, the F_1 generation is white—this time albinic white, mutants. W and N both being destroyed, these animals are nulliplex and breed according to the familiar formula.

As still another alternative, let W exist in still larger quantities and the mating take place; not only is all of N destroyed but there is an excess of W which gives some areas of duplex dominant white not holding the pigmented color as a recessive trait—in quite the same manner as the Shorthorns designated in this study as type No. 9 possess a coat solid white, some areas of which are dominant white not covering the red and the remainder of the areas are albinic white. A still greater amount of W will apparently effect the total destruction of N, making the offspring in the entire coat duplex dominant white, not holding N latent in the gametes and not capable of "reversion."

Let the antibody exist in very small quantity, insufficiently large to inhibit the ontogenesis of N, and let fertilization take place. It is conceivable that the antibody in such small quantity might have the same effect upon N as alcohol has upon an enzyme, in which case N would play its usual part in ontogenesis, but, being constantly harassed by W, would finally be inhibited or destroyed. The F_1 generation would then show senile grayness, as in man; here again the most superficial tissues are first attacked. If the antibody (W) is a trifle more concentrated the F generation will be born pigmented, but will develop juvenile white, as with the white horse, which as previously described is born with pigmented hair and skin—the skin remaining black and the hair turning white. Thus the process seems to be progressive, depending upon different intrusions de novo—"mutations"—and different inheritance lines for the presentation of various quantities of the antibody effecting the destruction of N in a definitely progressive ontogenetic, area and tissue sequence.

This is the hypothetical picture of intra-zygotic reaction

demanded by the somatic behavior in inheritance of coat pigments and patterns in Shorthorn cattle and in the other instances above cited.

Now, let some further observations be reported and then fitted to this conception for its support or rejection.

In the *Breeders' Gazette* (April 12, 1911) in response to an inquiry concerning the behavior in inheritance, with special reference to the possibility of spotted offspring of a white stallion, described as follows:

He is white with pink skin and would be albino but for a very few small specks in the skin and his dark eyes.

Dr. W. E. Castle answers:

The dark-eyed white condition is closely related to the piebald condition. It may indeed be regarded as an extreme variation of the piebald state in which the white spots cover the entire body except the eye. Most black-eyed white animals produce a certain number of piebald offspring, even when bred to animals exactly like themselves.

In reply to a request, W. P. Newell, of Washburn, Ill., the owner of the white stallion, supplies the following data:

The albino offspring of my stallion do not have pink eyes, but have "glass" or "watch" eyes.

Their hoofs are white or flesh color; there are no spots in the skin and not a colored hair on them. Not all of his white colts are albinos, some of them have a few colored hairs in mane or ears; these I do not refer to as albinos.

As a two-year-old this stallion was bred to six mares. Each one of these six produced a white colt.

As a three-year-old he had thirty-nine mares; got thirty-three in foal. About half of these were white, the others solid colors. These mares were very ordinary and of all colors, every size, shape and age. Following are a few of the instances: Bay mare got white colt; bay got black colt; two blacks got white colts; black got black colt; white and buckskin spot got pure albino; dapple gray got white colt; flea-bitten gray got white colt; three or more brown mares got white colts; two or more brown mares got brown colts; brown mare got pure albino; one sorrel got pure albino; one sorrel got brown colt. This will give you an idea of how his colts are colored.

Nothing is given and not much can be deduced con-

cerning the gametic make-up of these brood mares, but this interesting stallion seems to be barely on the dominant white side of the critical border between dominant white and albinic white. Had the whitening factor been a little more concentrated in the zygote giving rise to him, doubtless the ontogenesis of his choroid would have been inhibited or destroyed, the determiner for much of his more superficial pigmentation would have been destroyed and he would have been a *true* albino. Some of his germ cells seem to contain the antibody W in quantity and distribution adequate to inhibiting the quantitatively definite determiner for pigmentation found in some of the gametes of many pigmented mares; others of his gametes seem to lack this specific antibody, having in its place a determiner for dark pigmentation, hence, he is apparently simplex with reference to his dominant white determiners. If one of his gametes possessing W unites with a mare's gamete possessing pigmentation determiners greater than the quantitatively definite determiner above referred to, the inhibition will either not take place or it will take place incompletely—in the latter case resulting in some modification of the solid-color coat and skin condition. If the mare's gamete possessing less of the pigmentation determiners than the optimum quantity above referred to meets one of the stallion's gametes possessing W, the offspring will be white—dominant if the relative concentration of the determiner and the antibody is such as to cause only inhibition; recessive, *i. e.*, "albinic" if reaction occurs.

Let us consider the criteria of albinism. The general conception among investigators and writers on the subject seems to be that all strains of albinos have originated through dropping from the germ-plasm determiners for pigmentation previously possessed, rather than to have descended from ancestral types *never* possessing such pigmentation. Generally an animal is designated as "albino" when inhibition and reaction

have covered the entire skin, hair, nail and eye pigments. Castle[18] in his "Heredity of Coat Characters in Guinea-Pigs and Rabbits," excepts "centrifugal" areas. There is, moreover, no reason to believe that the pink eye of an animal may not result from the inhibition of the pigment determiner as well as from its destruction. In the progressive development of whiteness from senile white, juvenile white, dominant white covering pigment, albinic white, to dominant white not covering pigment, there seems to be, as we have seen, a species of tissue resistance as well as of area progression to this inhibition and reaction; the pigment of the deeper tissues being more generally resistant, or at least slower or later in succumbing to the attacks of the antibody. These deeper tissues, when dark and covered by the pigmentless tissues, give rise to a condition that is proved by experimental breeding generally to be dominant white. This is quite consistent with the present conception, for if the skin below is still pigmented it is quite probable that the hair pigments are only inhibited and not destroyed, and by the time the inhibiting process reaches the choroid, the destroying process is probably quite complete in the hair, and the animal is quite properly designated as an "albino"—recessive white. It must be borne in mind, however, that albinism may be either partial or complete; it may affect the entire coat color or it may affect only a limited area or a specific tissue. In partial albinism the eye is often blue—the absence of superficial pigments but presence of the deeper. Thus albinos become of great interest, and the study of their behavior very complicated, on account of this nascency of mutation. The intricate organization of the gamete can be determined only by the study of its ontogenetic sequence and end which, however, strongly suggest that chemical bodies within the germ cell behave exactly as such bodies within the test tubes of the laboratory. The disturbance of a single determiner may

[18] "Heredity of Coat Characters in Guinea-pigs and Rabbits," p. 9.

cause an accompanying correlation in something like the following manner: Consider the determiner for some definite somatic structure in a germ cell of one parent to be destroyed by an antibody analogously placed in the germ cell of the other parent; this chemical reaction must leave a product, which product it is conceivable may cause considerable havoc in so intricate a mechanism. There is no reason to believe that this product would of necessity confine itself to reactions with determiners first attacked; it might indeed be conceived to disturb or to destroy certain determiners for other tissues and forms.

The Silkie fowl seems to have received a very severe and peculiar upset in its determiners for pigmentation—note its black eyes and black deeply seated body pigments, together with its "albinic" plumage. Neither is there any probability, except by chance, of parallelism or similarity between the mechanical or chemical cause of such reaction and the resulting determiners—a notion savoring somewhat of the earlier conceptions prevalent in some quarters, of ante-natal influence—for Weismann[19] experimenting with *Vanessa* appears to have effected *color changes* by means of *temperature* and Tower[20] to have permanently upset that portion of the germ plasm of *Leptinotarsa* determining *pigmentation* by means of *humidity and temperature*. Thus, units may be made and unmade, and thus a foreign body or force entering a germ cell may conceivably cause a long series of reactions, each product becoming a new reagent affecting the determiners of many forms and tissues, if by chance lethal damage is not done before equilibrium is reached.

Moore in his paper "A Biochemical Conception of Dominance," says:

When fertilization occurs, the germ cells bring into contact certain substances which are set free to react upon each other. Some of these

[19] "Germ Plasm," p. 379.

[20] "An Investigation in Chrysomelid Beetles of the Genus *Leptinotarsa*."

substances may react simply with other substances and obey the Guldberg-Waage law of mass action, while others are of the nature of enzymes (ferments) and accelerate reactions which are already going forward at a very slow rate.[21]

It has been many times demonstrated that a positive determiner in a gamete of a simplex individual is not as "pure" as one from a duplex individual; furthermore, a soma developed from a zygote made up of a gamete containing a positive determiner, and another characterized by its absence, is not as strong in the character in question as one produced by two duplex parents. Thus, Davenport[22] has shown that in mating dominant white fowls with pigmented fowls there is often an "imperfection of dominance," giving rise to some more or less scattered pigmentation in F_1; this he demonstrated experimentally and, among other things, finds that

> Two white Leghorns crossed by a black Minorca produced only white hybrids, but the female hybrids at least had some black feathers. . . . No barring resulted from crossing white Leghorn with . . . black Minorca. . . . Of 26 hybrids between black Cochin and white Leghorn, 8 were barred black and white.

And he concludes that—

> alongside of dominance we must place an important modifying factor—the factor of the strength or potency of the representative of the given character in the germ plasm. This is clearly a variable quantity. If it is very potent we get a typically Mendelian result but if it is weak, we will have imperfect dominance or failure to develop altogether.

Thus the determiner for pigmentation in the black Cochin seems to be more concentrated than the same determiner in the black Minorca. Or is it possible that the antibody, although present in quantities theoretically in excess of the amount necessary for complete inhibition, fails to effect such inhibition completely for the same reason that the analogous phenomenon, due to some

[21] "A Biochemical Conception of Dominance," University of California Publications in Physiology, Vol. 4, No. 3, p. 11.

[22] "The Imperfection of Dominance," *American Breeders' Magazine*, Vol. 1, No. 1, p. 42.

mechanical necessity, is commonly observed in chemical experiments?

Obviously, the mass of the determiner for pigmentation is as potent a factor in determining the end result as the mass of the destroying antibody. The kind or quality of the pigment seems also to be a factor; the yellow or sorrel pigments seem to be destroyed more readily than the black or brown. It is also apparent that, due to a difference in the relative mass of the determiner and the antibody in the zygote, one cross may affect total destruction of the pigment while another parallel or reciprocal one may not. Thus, as above mentioned, Davenport's white Leghorn on black Minorca cross gave only white or nearly white offspring, while his parallel cross, viz., white Leghorn on black Cochin, gave considerable black pigment in the offspring. It has also been observed that the barred Plymouth Rock male, which is much less heavily pigmented than the female, when mated with a white Leghorn female gives only white offspring, but the reciprocal cross, viz., the white Leghorn male on the barred Plymouth Rock female gives barred, mottled, gray, creamy and white offspring regardless of sex. In this latter mating the two gametic elements, viz., the determiner for pigmentation and the destroying antibody, seem to be present in quite closely chemically balanced masses and it would be interesting to know whether in this cross the fluctuations across the color line are due to accidental variations in the strength of the individual gametic elements in question or to the Mendelian phenomenon.

There is still another white possessed by birds and mammals known as "structural white," characterizing some arctic animals such as the arctic fox, which is white the year around, and the arctic hare and the ptarmigan, which are pigmented at one season and white at the other. It would be interesting to know whether the fur and feathers of these animals in their unpigmented phases possess oxidized pigments. There are, more-

over white pea fowls. The gorgeous hues of the common pea fowl are due both to pigments and to defraction and it would be interesting to know whether the white pea fowl has lost its pigments or defraction surfaces, or both.

Animals of heavy pigmentation—as the blackbird, the crow and the negro—are said to be more subject to pre-senile and albinic white than others less heavily pigmented. Enzymes may be inhibited or destroyed by an excess of their own products. May it be indeed that the antibody (W) is itself a product of the determiner (N)?

To throw further light upon the whole problem, among other things, a careful study should be made of the behavior in inheritance of the age of graying of the hair and beard in man. If the conclusion of this paper presents a true picture, early graying of the hair and beard will be found to be dominant over the later manifestation of the same phenomenon. It is further anticipated that a chemical analysis of senile white and juvenile white tissues will show the same absence of somatic pigment as Gortner[23] has shown in his study of albinic and dominant whites.

In this study of Shorthorn cattle nine theoretical gametic coat-color types are defined. As previously stated, the striking fact is this: The roan of type No. 3 (which is reciprocally colored as compared with the ordinary color pattern of cattle) is *never* observed, and quite probably the red of type 2 is also missing. The reason is apparently as follows: The antibody inhibiting and destroying the determiner R (for red pigment) first attacks through mechanical and chemical necessities the determiner for coat pigment in the somatic areas of Set 1 (roughly—flank, heart girth, forehead) and progresses systematically through the areas of Set 2 (roughly—underline, barrel, legs and quarters, head and neck) according to the following scheme:

[23] "Spiegler's 'White Melanin' as related to Dominant or Recessive White," The American Naturalist, Vol. XLIV, p. 501.

TABLE VIII

Class or Stage	Amount of Antibody Present	Gametic Formula for Areas of First Attack. (Set 1)	Gametic Formula for Areas of Later Attack. (Set 2)	Number of Inheritance Units in Entire Coat Pigmentation	Examples of Some Breeds of Cattle Representative of the Respective Resting Stages of the Whitening Process
1.	None or too little to start inhibition.	w_2P_2	w_2P_2	One.	Angus and solid black breeds generally.
2.	Enough to inhibit the determiner for pigmentation of the areas of Set 1.	W_2P_2	w_2P_2	Two or two groups.	Holstein and spotted breeds generally.
3.	Enough more to inhibit the determiner for pigmentation of the areas of Set 2.	W_2P_2	W_2P_2	One.	White park cattle of Britain.
4.	Enough more to start reaction and to destroy the determiner for pigmentation of the areas of Set 1.	w_2p_2	W_2P_2	Two or two groups.	Not represented by any breed nor ever observed in mongrels.
5.	Enough more to continue reaction and to destroy the determiner for pigmentation of the areas of Set 2.	w_2p_2	w_2p_2	One.	Occasional albinos.
6.	Enough more to deposit excess of antibody in place of determiner for pigmentation of areas of Set 1.	W_2p_2	w_2p_2	Two or two groups.	White Shorthorns of Type 9 of this paper.
7.	Enough more to deposit excess of antibody in place of determiner for pigmentation of areas of Set 2.	W_2p_2	W_2p_2	One.	Remotely possible that some strains of British white park cattle are of this type.

W = presence of antibody. P = presence of determiner for pigmentation.
w = absence of antibody. p = absence of determiner for pigmentation.

In Shorthorn cattle, classes 4, 5 and 7 of this table are not met with, neither are conditions parallel to class 4 ever observed in any other mammals. The further explanation may be as follows: Reaction between W and R does not begin until an excess of W is present (a condition not hard to parallel in the chemical laboratory) but when reaction does begin it is quite rapid, destroying all of R and most likely leaving an excess of W at the point of first attack. This would eliminate Class 4 (type 3 of the series previously described) and Class 5 (pure albinos) of this table. There may be "albino" cattle;

Pearson[24] reported a rumor of a herd of such but he was unable to locate it. Wilcox and Smith[25] describe a race of white cattle—Polled Albino—made by crossing a white Shorthorn cow with a polled bull of unknown breeding. The Swedish cattle were thought to possess "pink eyes" and if so were probably albinic in their entire coat; the Polled Albinos are doubtless "partial albinos." White Shorthorn cattle are generally blue-eyed, however, a considerable percentage are brown eyed.

The following chart of the ancestry and offspring of "White Rose," the first cow purchased by Mr. J. F. Hagaman, of Leonard, Mich., is prepared from data supplied by him:

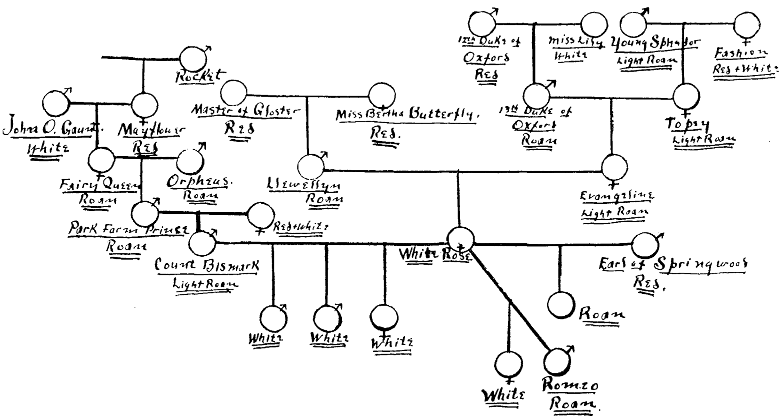

CHART NO. 3

He also writes:

I purchased another cow, Daisy Dean, red and white. All her ancestors were red, red and white, or roans. She was bred to Park Farm Prince (roan) and produced twin bull calves both *white*. They were exactly alike and were made into steers. A drover took them to Boston where they sold for $500. . . . All the white calves had *blue* eyes, *flesh-colored* noses and *light* skins.

Dr. D. M. Kipps, of Fort Royal, Va., writes:

I feel sure I never had a white Shorthorn with a *black* nose; I had one or two that had slightly cloudy noses. I think every one had pink

[24] "On the Inheritance of Coat-Colour in Cattle," *Biometrika*, 1905–06, p. 436.

[25] "Farmers' Cyclopedia of Live Stock," p. 369.

skin underlaying the white coat and *nearly* every one had slightly reddish hair on the inside and around the outer rim or auricle of the ear.

Mr. J. H. Hawkins, of Xenia, O., writes:

Will say I have never seen a white Shorthorn with pink eyes. My white Shorthorns have pure white coats, pink skins and brown eyes. As to black noses, they are not a rare thing to see . . . now and then.

Shorthorn cattle were made from the Anglo-Saxon reds —Class 1 of the above table No. VIII; the Flecking— Class 6; the Romano-British—Class 3, and probably some other primitive types. Evidently none of the breeds of domestic cattle has yet reached stage 7, *i. e.*, solid dominant white not capable of reversion. The Shorthorns of to-day present all the possible combinations of Classes 1, 2, 3 and 6.

In reference to the fact that the race of duplex yellow mice has never been produced and in view of what Castle[26] says,—viz., that the union between germ cells carrying only yellow pigment is doubtless affected, still all such germ cells from some cause are doomed to destruction, may it not be that in so delicately adjusted a mechanism two of these specific determiners present a lethal dose? May this not be one of the causes of the limits of hybridization and of the sterility of hybrids? The germ cells are doubtless distinguished by both a specific architectural and a specific chemical organization of the greatest nicety of adjustment and balance. The closest approach in the chemical world to their behavior is that of the enzymes, which, though not entering into reactions, may bring them about; while in the course of its own continuity the germ plasm gives rise to cells of its own kind, supplying them with bodies behaving in an enzyme-like manner sufficient for their own continuity and for a long series of ontogenetic processes.

It is obvious that a disturbance of some consequence would follow the advent of a foreign body or of unusual

[26] "Modified Mendelian Ratio among Yellow Mice," *Science*, December 16, 1910, Vol. XXXII, p. 868.

quantities of a normal body presented either by hybridizing or by osmotic intrusion; perhaps it may clarify the conception to make analogy to the degree and sequence of reactions in test-tubes or other containers of more complicated design holding the same chemical in varying quantities, places and degrees of nascency, wrought by the addition of varying quantities of the same reagent. The inhibitions and reactions expected from such conditions would begin at definite places, would continue in a more or less definite succession characteristic of each set of conditions, would complete a reaction first in definite parts and would proceed with varying degrees of speed, might effect a reaction and deposit an excess of reagent in some parts before even reaching other parts. Let there be an equilibrium following reaction; then add more of the reagent or of the chemical acted upon and it is easy to picture subsequent reactions all of which are closely analogous to the processes which the study of Shorthorn cattle leads us to believe have taken place within their gametes and zygotes. The behavior of their coat color and that of many other animals demand such behavior within the zygote. Thus such processes seem to account for the coarse mosaic or the spotted, and the fine mosaic or the roan color coat, the imperfection of dominance, reversion, the origin of the mottling and barring of fowls, the progressive dappling of horses, the peculiar behavior of "albino" guinea pigs, the characteristic behavior of coat pigment and patterns in Shorthorn cattle, and other similar phenomena. The stag, but not the doe, caribou possesses a beautiful white collar, and it may be that sex-limited characters are wrought by a sort of "havoc" or series of progressive reactions, preceding chemical equilibrium caused by the introduction of the essential sex-determiners.

A human family is recorded[27] in which a pre-senile gray spot occurs in the beard of the left cheek of many of its male members. In possible explanation, it is sug-

[27] Files Eugenics Record Office, Cold Spring Harbor, L. I.

gested that a small quantity of some antibody somehow inhibited or destroyed a portion of the determiner for pigmentation in the germ cell from which this family sprung. This indeed points toward a possibility that unit characters may arise from a partial destruction of larger units; that a determiner for a unit character behaving precisely in unit fashion may be a complex capable of being shattered into a large number of independently behaving characters. Small as the germ cell is and quantitatively insignificant as the determiner for the skin and hair pigment must be, the facts demand that this body consist of many molecules arranged in definite structure, each one destined for a somewhat definite ontogenetic process leading to a definite somatic end. Thus the often inherited specific color mark seems to indicate that a color pattern once produced—no matter how intricate or complex—will reproduce itself exactly until its determiners are disturbed by unbalanced bodies or forces presented by fertilization or otherwise.

The Shorthorns are a race of white cattle caught in the making and preserved in the nascent state by a rigid selection. It is thus conceivable that mutations may arise constantly, and that they may be progressive in character. Complications resulting in somatic effect are legion, but nothing occurs in the germ cell giving rise to new characters, splitting up and combining others and dropping out still others, that can not be analogously pictured with the simple operations of the chemical laboratory, and as Shull's[28] illuminating "Simple Chemical Device to Illustrate Mendelian Inheritance" seems to indicate, the analogy is too constant and too far-reaching to be cast aside as a mere pedagogical device. It may indeed be a simple statement of facts of intra-gametic and zygotic behavior and the analogy may no longer be needed to picture the actual conditions.

[28] *The Plant World*, Vol. 12, pp. 145–153, July, 1909, and companion paper, "The 'Presence and Absence' Hypothesis," THE AMERICAN NATURALIST, Vol. XLIII, No. 511, pp. 410–419, July, 1909.

The evidence of this study of Shorthorn cattle is to support that theory of unit segregation incompatible with a somatic blend in the *ultimate* unit, and that theory of heredity permitting intra-zygotic inhibition and reaction *in response to specific set conditions.*

The mutually corroborative evidence of the authentic history of this breed of cattle, the behavior of their coat pigments and patterns as recorded in the most extended authentic records of pedigree breeding of domestic animals, analogy to the occurrence and behavior of pigments in other animals, and the close fitting of the final working hypothesis, amply justify the following conclusions:

1. Shorthorn cattle as a race possess two kinds of white hair. (A) White, dominant to all pigments (analogous to the white of the Leghorn fowl) in a series of areas varying somewhat in size and shape but in a given individual always definite and genetically independent—a few at the front flank belt, a larger number or larger areas about the rear flank belt, a few along the underline and a fine network covering the remainder of the body. A few animals from their Romano-British ancestry have the entire coat of dominant white. An area of dominant white may be duplex or it may be simplex. In the former case its possessor will throw only gametes with determiners for dominant white; in the latter alternately gametes with determiners for dominant white and for red. (B) White, recessive to all pigments (analogous to the white of the Silkie fowl) in a series of definite areas generally smaller than those of the dominant white, forming a fine network about the neck and head, the sides and back, and the hind quarters and legs—quite precisely excluding the areas of the dominant white network. From their Dutch ancestry, this mosaic may in some strains be quite coarse. It is doubtful if a strain albinic white in its entire coat exists within the Shorthorn breed.

2. The color effect of an individual Shorthorn is determined by the registering of fortuitously one of the alternate color phases of each of the genetically independent

color areas gametically possessed by each of the two parents, together with such intra-zygotic inhibitions and reactions between the determiner for pigmentation (R) and the antibody (W) as may result from definite concentrations and intimacy of these two bodies presented by the two parents upon the formation of the zygote.